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discrete cosine transforms image coding vector quantisation JPEG-coded images boundary pixel **difference** blocking **artifact** reduction low-bit-rate coded JPEG image block-boundary-discontinuity criterion overlapped sub-laplacian distribution post-proc method postprocessing method **quantization** error statistical property visual quali

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Blocking Artifact Reduction in JPEG-Coded Images

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Abstract

We proposed the post-processing method to reduce the blocking artifact in low-bitrate coded JPEG images, which is based on minimum block-boundary-discontinuity criterion. We analyzed the statistical property of block boundary pixel difference, classified all blocks into one of two types using OSLD (Overlapped Sub-Laplacian Distribution), and compensated the quantization error depending on the type of block, adaptively. Our post-processing method can provide better visual quality as well as PSNR than any other method.

1. Introduction

The block-based DCT (B-DCT) scheme is used in many image and video compression standard including JPEG, ITU-T H.263, MPEG [1-2]. B-DCT divides the image into 8 × 8 blocks of pixels and transforms each block and quanitze the coefficients. Since each block is encoded independently, there is visible artifact along block boundaries of the decoded image, particularly, when the image is encoded with low-bitrate. This phenomenon is called blocking artifact.

Many post-processing methods have been proposed to reduce the blocking artifact [3-6]. The minimum block boundary method [3] especially has a weak point in edge areas. Even though they used the weighting value to reduce the above effect, they could not control the degree of compensation effectively. The MSDS method [4], which estimate the lost DCT coefficients at the low frequency areas, can't choose constraint parameter since that is dependent on both an input image and compression ratio. The local CLS method [5] shows better visual quality at edge areas but has poor visual quality at homogeneous areas.

In this paper, we investigate the statistical property of difference values of quantized block-boundary pixels in JPEG-coded images, classify all blocks into one of two types using OSLD, and we compensate the quantization error depending on the type of block, adaptively.

2. The Proposed Post-processing Method

The proposed method consists of three steps as following; ***Step 1)*** Classify each boundary pixel difference values into two types, i.e. TYPE-*1*, TYPE-*2*. ***Step 2)*** Estimate quantization error in each block. ***Step 3)*** Compensate quantized pixel values by weighting the estimated error with λ_k if the current block is contained in TYPE-*k*

2.1 Discontinuity Measure

As mentioned earlier, the blocking artifact results in discontinuity between block boundaries. Based on this observation, the discontinuity $QDiff_{i,j}$ of current block is measured by (1) [3]

$$\begin{aligned} QDiff_{i,j} &= \sum_{k=0}^{N-1}\{[f_{i,j-1}^{Q}(k,N-1) - f_{i,j}^{Q}(k,0)]^2 \\ &\quad + [f_{i,j+1}^{Q}(k,0) - f_{i,j}^{Q}(k,N-1)]^2 \\ &\quad + [f_{i-1,j}^{Q}(N-1,k) - f_{i,j}^{Q}(0,k)]^2 \\ &\quad + [f_{i+1,j}^{Q}(0,k) - f_{i,j}^{Q}(N-1-k)]^2\} \\ &= \sum_{k=0}^{N-1}\{[d_{i,j-1}^{Q}(k)]^2 + [d_{i,j+1}^{Q}(k)]^2 \\ &\quad + [d_{i-1,j}^{Q}(k)]^2 + [d_{i+1,j}^{Q}(k)]^2\} \end{aligned} \tag{1}$$

where $f_{i,j}^{Q}(x,y)$ is a quantized pixel values of the (*x*,*y*)-th pixel in the (*i*,*j*)-th block $B_{i,j}$, and *N*=8 in this paper because we apply to JPEG codec. Let $d_{i,j\pm1}^{Q}$'s and $d_{i\pm1,j}^{Q}$'s be elements of a set $S_{i,j}$ and $Diff(x)$ be the *x*-th element in $S_{i,j}$;

$$\begin{aligned} S_{i,j} = \{&d_{i,j-1}^{Q}(0)\cdots d_{i,j-1}^{Q}(N-1)d_{i+1,j}^{Q}(0)\cdots d_{i+1,j}^{Q}(N-1) \\ &d_{i,j+1}^{Q}(0)..d_{i,j+1}^{Q}(N-1)d_{i-1,j}^{Q}(0)..d_{i-1,j}^{Q}(N-1)\} \end{aligned} \tag{2}$$

Figure 1 shows $Diff(x)$'s in $B_{i,j}$.

2.2 Overlapped Sub-Laplacian Distribution (OSLD) and Block Classification

A categorization of current block is firstly processed using the characteristic of quantized pixel difference values through block boundaries.

It is well known that the distribution of pixel value differences in an image is Laplacian, but quantized image

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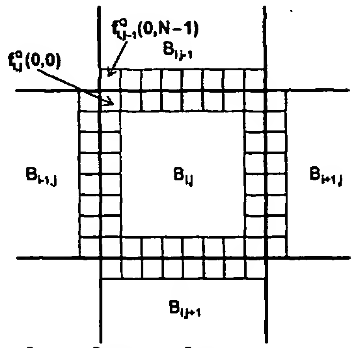
has different distribution as shown in Figure 2.



• $d^{c}_{i,j-1}(0)=f^{c}_{i,j-1}(0,N-1)-f^{c}_{i,j}(0,0)$

Figure 1. $Diff(x)$ **in** $B_{i,j}$

Since it is approximately the sum of four sub-Laplacians of which the centers depend on not the input image but the quantization factor (QF), the distribution of the JPEG-coded image can be represented by (3), which is called "Overlapped Sub-Laplacian Distribution (OSLD)" in [6].

$$g(x)=\sum_{k=-3}^{3}\frac{1}{\sqrt{2\sigma_k^2}}\exp\left(-\frac{\sqrt{2}}{\sigma_k}\left|x-2k\times QF\right|\right) \quad (3)$$

Since the OSLD is near to symmetric, the absolute value of $Diff(x)$ is considered. Therefore, there exist four regions, which are separated by three intersection values as following: $|Diff(x)|<Th_0$, $Th_0\le|Diff(x)|<Th_1$, $Th_1\le|Diff(x)|<Th_2$, and $|Diff(x)|\ge Th_2$, where

$$Th_k=\frac{2}{1+\alpha_k}\left\{\left[(1+\alpha_k)k+\alpha_k\right]\times QF-\frac{\sigma_k}{2\sqrt{2}}\ln\alpha_k\right\} \quad (4)$$

and $\alpha_k=\sigma_k/\sigma_{k+1}, k=0,1,2$. We can empirically approximate (4) into (5) to reduce the complexity. Distributions shown in Figure 2 support the above approximations.

$$Th_k\approx(2k+1)\times QF,\ k=0,1,2 \quad (5)$$

Then, we classify $Diff(x)$'s into two sets by (6): one corresponds to a set R_1 of homogeneous pixel pairs and the other a set R_2 of edged pixel pairs [6].

$$\begin{aligned}&\text{if}\ (Diff(x)\le Th_1)\ \ Diff(x)\in R_1;\\&\text{else}\ \ Diff(x)\in R_2;\end{aligned} \quad (6)$$

Then, the block is classified into two types: TYPE-*1* and TYPE-*2*. If there are few $Diff(x)$'s in R_2, the block belongs to TYPE-*1*. If the size of R_2 is greater than m, the block belongs to TYPE-*2*. Since there can exist no complex object in the block, we can assume that m is very small. In this paper, we use m=4.

Figure 3 shows a flow chart of the block classification process applied to each block.

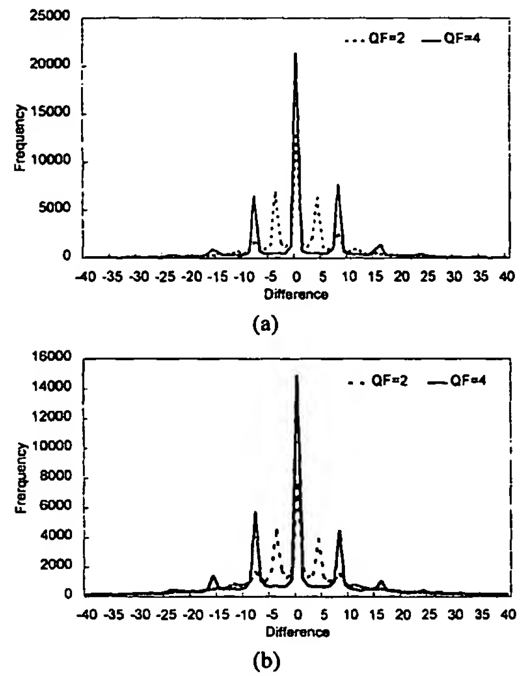


Figure 2. Distributions of block-boundary pixel-pairs difference values in JPEG-coded images: (a) Lena, and (b) Barbara

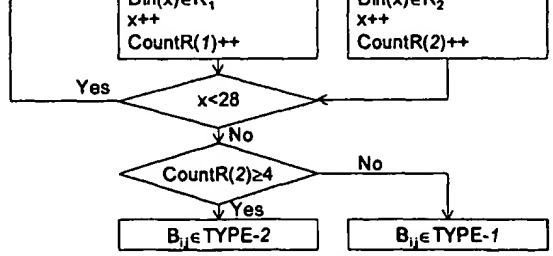


Figure 3. Flow chart of the block classification process in each block

White and texture blocks in Figure 4 correspond to TYPE-*1* and TYPE-*2* blocks in Lena and MIT images, respectively.

Figure 4. Classification of blocks in the JPEG-coded Lena and MIT images (*QF*=4) : TYPE-*1* blocks are colored with white.

3. Quantization Error Estimation

The quantization error $\Delta f_{i,j}^{Q}(x,y)$ of each pixel in $B_{i,j}$ can be estimated by minimizing (1) in ***Step 2*** which is defined as following;

$$\Delta f_{i,j}^{Q}(x,y) = f_{i,j}(x,y) - f_{i,j}^{Q}(x,y) \qquad (7)$$

Even though $\Delta f_{i,j}^{Q}(x,y)$ is estimated minimizing (1), it is not reasonable to use $\Delta f_{i,j}^{Q}(x,y)$ itself since $QDiff_{i,j}$ of homogeneous areas results in pure quantization error while $QDiff_{i,j}$ of edge areas is sum of quantization error and original pixel difference [6]. Thus, $\Delta f_{i,j}^{Q}(x,y)$ obtained by minimizing (1) must be modified in proportion to pure quantization error because it can be assumed that $\Delta f_{i,j}^{Q}(x,y)$ contains only quantization errors in the homogeneous blocks, while it is dominated by original pixel value differences instead of quantization errors in the edge blocks. To prevent side effect such as blurring in edges, another distortion in inter-block, the estimated error is weighted by λ_k in this paper, where k is the type number of the block. Therefore, we can reduce the blocking artifact with preserving edgeness since the weight value λ_k is not fixed to a number but is chosen based on the characteristics of the block. The reconstructed pixel value $\hat{f}_{i,j}(x,y)$ can be computed by (8) multiplying λ_k to the estimated error if the block is contained in TYPE-*k*.

$$\hat{f}_{i,j}(x,y) = f_{i,j}^{Q}(x,y) + \lambda_k \Delta f_{i,j}^{Q}(x,y) \qquad (8)$$

where $\lambda_1 = 1.0$, and $\lambda_2 = 0.4$ in this paper.

In general, only a DC and a few lower frequency components are compensated since most energy is concentrated on them. A DC and three low frequency components are considered in this paper.

4. Experimental Results

The proposed method is applied to the decoded images to evaluate the performance. The quantization table recommended in [1] is used. In Figure 5 (b), block boundaries are quite noticeable in her cheek and shoulder. The proposed method is compared with two post-processing methods such as the Zakhor's MSDS, and the Jeon's method [3]. In Figure 5 (c), result of the MSDS requires the low-pass filtering method after the low frequency DCT coefficient optimization since it does not take care of original pixel differences in edge areas. Even though the Jeon's method with weight value $\lambda = 0.5$ does not induce the side effect, we can still see severe blockiness in homogeneous areas as shown in Figure 5 (d). Using the proposed method, the blocking artifact can significantly be removed in her cheek, and shoulder areas as shown Figure 5 (e). Figure 6 shows a part of the JPEG-coded Lena image after post-processing. We can see that the proposed scheme can provide better picture quality than any other one.

PSNR values of each scheme are summarized in Table 1. Our scheme produces the better PSNR than other methods.

Table 1. The PSNR values in various post-processing methods (unit : dB)

Scheme \ Images	Lena	MIT	Barbara
Quantized	28.23	28.52	24.10
MSDS	27.84	28.03	23.93
Jeon's	27.63	26.95	23.82
Proposed	28.20	28.04	24.18

5. Conclusions

In this paper, we proposed a post-processing method to reduce the blocking artifact in low-bitrate coded JPEG images. The statistical characteristic of block-boundary pixel difference values, which we called OSLD, was applied to classify all the blocks into two types: TYPE-*1* and TYPE-*2*. After classification, quantization error values were estimated with minimizing block-boundary-discontinuity. The estimated error was weighted in order to reduce the blocking artifact with preserving edgeness before adding it to the quantized value. The weight value λ_k was chosen based on the characteristics of the block, that is, whether the block was TYPE-*1* or not. With neither a directional low-pass filter nor an edge enhancement filter in the edge area, the proposed method could provide better visual look as well as better PSNR values than other methods referred in this paper.

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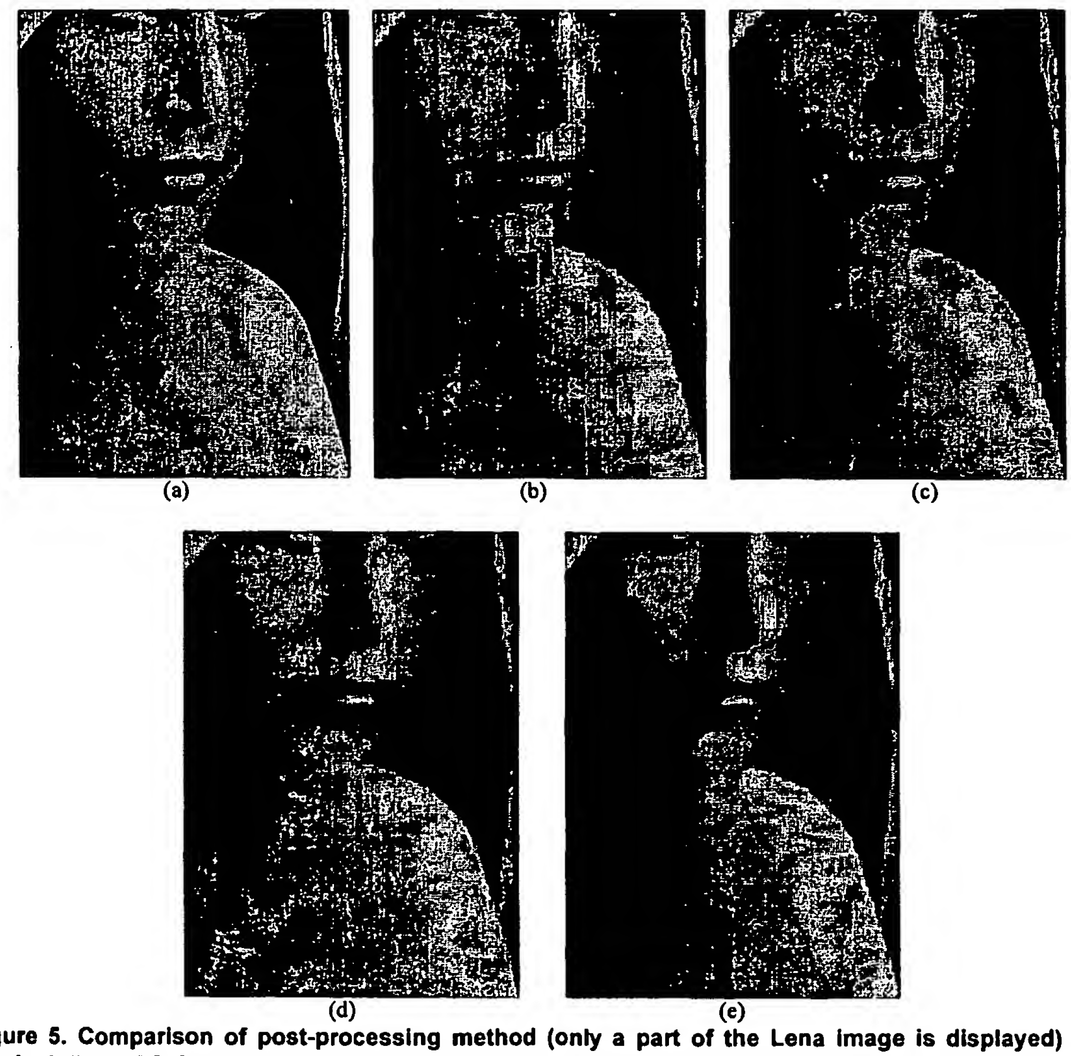
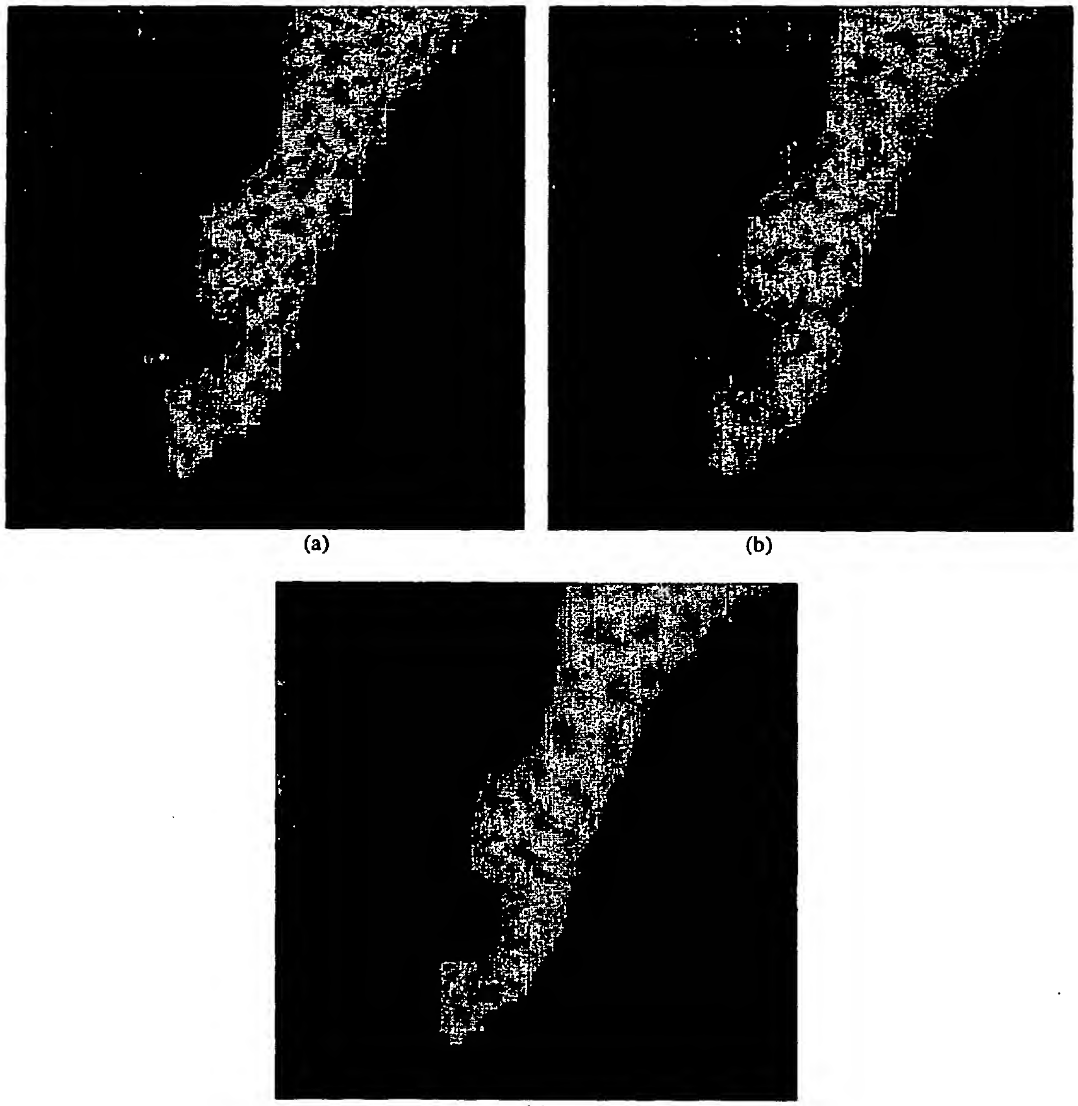


Figure 5. Comparison of post-processing method (only a part of the Lena image is displayed) : (a) Original, (b) JPEG-Coded (*QF*=4), (c) MSDS, (d) Jeon's with $\lambda = 0.5$, and (e) proposed method



(c)

Figure 6. Magnified Lena Images : (a) JPEG-Coded (*QF*=4), (b) MSDS, and (c) proposed method